Investigations of the hydrogen atom

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G. F. Bassani, M. Inguscio, and T. W. Hänsch (editors). *The Hydrogen Atom: Proceedings of The Symposium Held in Pisa, Italy, June 30-July 2, 1988*, Springer-Verlag, Berlin; Heidelberg; New York, 1989, 353 pp.

The history of the creation and development of quantum mechanics and of quantum electrodynamics is closely associated with investigations of the energy spectrum of the hydrogen atom and of hydrogen-like ions. Thus, the calculation of the fine structure of the hydrogen atom energy levels based on Dirac's relativistic theory of the electron, which agreed excellently with experiment, was one of the theory's first confirmations. Verification of the idea that the electron has an anomalous magnetic moment based on investigations of hyperfine splitting of levels can serve as another impressive example. The corresponding quantitative estimates made for the electron anomalous magnetic moment and the Lamb shift δ (H, $n = 2$) that are treated as manifestations of vacuum radiation effects furthered the development of renormalization theory, which forms the basis of quantum electrodynamics.

In the modern understanding, one must include among the hydrogen-like atoms the positive ions of the hydrogen isoelectron sequence, muonium ($e^-\mu^+$), positronium (e^-e^+), muon and pion hydrogen (μ^-p and π^-p), etc. In other words, hydrogen-like atoms are the simplest bound states of two particles interacting through an electromagnetic field, being the most accessible objects for verifying the different predictions of quantum electrodynamics.

Material from papers presented at an international symposium devoted to theoretical and experimental investigations of hydrogen-like atoms (at Pisa in June and July 1988) has gone into the volume under review.

The book under review appears to be unique in many respects. First, the wide representation of the participants of the symposium predetermined the scientific level and the breadth of the scope of questions under consideration. Second, the circumstance that, at present, an enormous amount of material has been published on this subject in a large number of original papers, among which there are extremely few reviews, and it is essentially accessible only to specialists, also indicates the timeliness of publishing such a book. Finally, third, the book reflects not only modern achievements in the investigations of the various properties of hydrogen-like atoms, but the prospects for their future development are also ascertained.

The volume consists of four sections.

The first of them is devoted to describing techniques for precision measurements in a hydrogen atom. Lamb shift δ (H, $n = 2$) measurements are represented by two papers. The measurement of δ by means of an original procedure, observation of the interference of two phase-shifted components of the 2P (or 2S) state of the hydrogen atom, was reported in one of them (Yu. L. Sokolov, USSR). The separate oscillating fields method suggested by N. Ramsey was used in the second paper (F. Pipkin, U.S.A.). We note that the error of the δ measurements by the "atomic interferometer" method is approximately five times smaller than the error of modern quantum electrodynamics calculations and is ~ 2 ppm (1 ppm $= 10^{-6}$). Five papers of this section are devoted to the use of laser Doppler-free two-photon spectroscopy for measuring transition frequencies in the Balmer series and the $2S_{1/2}-1S_{1/2}$ transition in hydrogen and deuterium that are used, in particular, to determine the Rydberg constant R_∞. The improvement of its value plays an important role, since R_∞ actually connects three fields of research; quantum theory, atomic spectroscopy, and measurements of fundamental physical constants. The most accurate value for it, equal to $R_\infty = 109{,}737.3157136(186)$, is presented in the paper by F. Viraben and colleagues (France). Original reports devoted to optical frequency standards and to studying the properties of individual hydrogen atoms by using different types of quadrupole Penning traps appeared in the final part of this section.

The second section of the volume is entirely devoted to experimental investigations of spectroscopically exotic atoms (positronium, muonium, muon atoms, and antiproton hydrogen). The latest achievements in spectroscopic measurements in muonium ($e^-\mu^+$) are considered in the paper by W. Hughes (U.S.A.). The purely lepton nature of muonium (unlike hydrogen, it does not contain hadrons, since μ^+ took the proton's place) enables one to calculate the hyperfine splitting (in the framework of quantum electrodynamics) in the ground state with a high degree of accuracy and, in combination with precision measurements of this value, to obtain a value of the fine structure constant with an error of ~ 0.15 ppm, which is comparable in accuracy with that which was found from the Josephson effect and the quantum Hall effect. The paper by E. Klempt (Federal Republic of Germany) on the properties of a bound "proton-antiproton" system with an emission spectrum lying in the x-ray region evokes much interest. The remaining papers of this section concern experimental methods for determining the frequencies and rates of decay for positronium (e^-e^+), and also investigations of the spectra of hydrogen-like atoms with large nuclear charges (of positive ions).

A comparative analysis of the values of α obtained both by using quantum electrodynamics and also by means of experiments that are completely independent of quantum electrodynamics is made in the paper by T. Kinoshita (U.S.A.) in the third section of the symposium. It is determined that, by retaining the $\sim\alpha^4$ terms in the expansion of the electron anomalous magnetic moment in powers of α, one can obtain a result for α with an error ~ 0.0082 ppm, which is a record value for accuracy of those known at present.

Those general properties which are inherent to the methods of quantum electrodynamics and quantum chromodynamics for examining the properties of the bound states of two-particle systems are discussed in this same section.

One can conditionally divide the fourth and last section of the book into two parts. Multiple photon transitions in hydrogen in a continuous spectrum and the processes of the interaction of hydrogen-like atoms with an intense electric field are considered in the first of them. The second part of this section is devoted to quantum chaos in a hydrogen atom in the presence of a strong magnetic field in which the value of the diamagnetic potential is compared with that of the Coulomb potential. One must note that mathematical modeling of quantum chaos in atoms became possible recently due to the appearance of high performance electronic computers and computer graphics.

On the whole, the book under review reflects the present stage in the development of research on the hydrogen-like atom, and will definitely be useful to a wide circle of specialists (to both theorists and experimenters) working in the fields of atomic spectroscopy, optics, quantum electrodynamics, and quantum metrology.

Translated by Frederick R. West